Journal of Applied Sciences, 2011
ISSN 1812-5654 / DOI: 10.3923/jas.2011.

Effect of Machining Parameters on Surface Roughness During Wet and DryWire-EDM of Stainless Steel

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Abstract: Surface integrity of machined parts is one of the major machining characteristics that play an important role in determining the quality of engineering components. It is a well-known fact that good quality surfaces improve the fatigue strength, corrosion and wear resistance of the workpiece. The purpose of this study was to investigate the effects of Wire-Eectrical Discharge Machining (WEDM) variables on surface topography of stainless steel. In the present work, the effects of pulse current and gap voltage on surface topography during wet and dry WEDM of stainless steel were investigated. It was evident that as the two process parameters increase the surface topography of the workpiece become worsens. The effect of both dry and wet machining conditions on the surface topography are also investigated and reported in this paper.

Key words: Dry WEDM,pulse current, gap voltage, surface topography, machining parameters, wet WEDM

INTRODUCTION

Electrical Discharge Machining (EDM) is the most widely known and used non-conventional machining technique for the manufacture of engineering components and parts from standard workpiece materials of any hardness. EDM removes metal through the action of electrical discharge of short duration and high current density between the tool and the workpiece in the presence of die electric fluid (Aspinwall *et al*., 2008). EDM has been proven to be especially valuable in the machining of super-tough, electrically conductive materials such as the new space-age alloys (Rebelo *et al*., 1998; Ho and Newman, 2003). Systems configured for die-sinking EDM using solid tool-electrodes or through a cutting system wire-cut EDM which employs a continuously moving wire-electrode, are relatively common (Rebelo *et al*., 1998).

In wire-EDM, the electrode is a continuously circulating brass or copper wire of about 0.1 mm diameter, which cuts the workpiece along a programmed path. Deionized water is used as dielectric fluid, which is directly injected around the workpiece and wire-electrode. The wire wear poses a lesser problem, because new ones due to the wire circulation continuously replace the wire. Wire-EDM is used for high-precision machining of extremely hard steels and exotic metals, mostly used by the mold-making tool and dies industries, particularly in the aerospace and electronics industries (Aspinwall *et al*., 2008; Rebelo *et al*., 1998; Suleiman *et al*., 2010). Wire-EDM is essentially a thermal process with a complex material-removal mechanism, involving the formation of a plasma channel between the tool (wire) and workpiece resulting in metallurgical transformations, residual tensile stresses and cracking. These properties determine one of the operational behaviours of a machined part which is known as surface integrity (Ho and Newman, 2003). According to Bagci and Isik (2006), in machining of parts, surface quality is one of the most specified customer requirements.

In wire-EDM, the quality of the machined part with respect to its precision and surface integrity, is not only related to the machining parameters of current, gap voltage, discharge duration, wire tension, wire speed, dielectric fluid and polarity, but also depends on machining techniques (dry or wet). Surface integrity of machined parts is one of the major machining characteristics that play an important role in determining the quality of engineering components. It is a well known fact that good quality surfaces improve the fatigue strength, corrosion and wear resistance of the workpiece (Onwubolu, 2005; Kanlayasiri and Boonmung, 2007; Suleiman *et al*., 2009; Guu and Hocheng, 2001; Ramulu *et al*., 2001).

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In view of the importance of surface integrity of any machined parts, it is therefore important to achieve better surface integrity during wire-EDM process. The purpose of this work is to investigate the effect of machining parameters on surface topography during wet and dry-wire-EDM of stainless steel. Many researchers have reported on the effect of machining parameters on surface topography during wire-EDM. Aspinwall *et al.* (2008) investigated workpiece surface roughness and integrity after wire-EDM of Ti-6Al-4V and Inconel 718. They reported an extremely low level of workpiece damage using wire-EDM employing ultra high frequency/short duration pulses. They also reported that recast material was evident with a very low thickness that could be removed by etching. Kanlayasiri and Boonmung (2007) worked on the effects of wire-EDM machining variables on surface roughness of newly developed DC 53-die steel their report shows that pulse on time and peak current are significant variables to the surface roughness of wire-EDMed DC53 die steel. It was reported that the surface roughness of the test specimen increases when pulse on time and peak current increase.

Mahapatra and Patnaik (2006) reported on the discharge current, pulse duration, pulse frequency, wire speed, wire tension, dielectric flow rate and interactions on maximization of MRR and minimization of surface roughness in WEDM process using Taguchi Method. According to the work of Puri and Bhattacharyya (2005) titled “modeling and analysis of white layer depth in a wire-EDM process”, the white layer depth in the workpiece increases with increasing pulse on-time during the first cut, while the white layer depth decreases with increasing pulse on-time during trim cutting. Velterop (2003) studied the effect of four sets of wire-EDM parameters on the surface topography and surface layer thickness. Thereafter, a set of wire-EDM parameters was chosen for the fatigue tests, which included reference specimens produced by abrasive jet machining. He concluded that wire-EDM significantly reduces the fatigue strength of precipitation hardening martensitic steel. He also reported that decreasing the severity of the wire-EDM parameters would probably not reduce the detrimental effect on fatigue strength. Veltrop recommended that finishing operation such as: grinding, polishing or chemical milling should be carried out to remove the modified surface layer, especially the brittle, untempered martensite. It can be observed that comparison of two methods of wet and dry wire-EDM are missing.

The present study investigates the effect of two machining methods of dry and wet wire-EDM on surface integrity. The effect of pulse current and gap voltage on surface roughness during wet and dry WEDM of stainless steel were also investigated.

MATERIALS AND METHODS

Material employed in this study was SUS 304, austenitic stainless steel. This material is used extensively in dies and moulds industries and well known for its good corrosion resistance. The chemical composition and mechanical properties of the material are given in Table 1 and 2, respectively. The workpiece material was prepared to 30×15×10 mm. Square shaped samples of size 12m×12mm with a depth of 10 mm were machined (wire-EDM).

After the two methods of dry and wet wire-EDM were carried out, the following measuring techniques were employed for assessing the surface integrity of the workpiece:

- **Surface roughness measurements:** The surface finish parameter employed to indicate the surface quality in this experiment was the arithmetic mean roughness (Ra). Workpiece surface roughness R_a was evaluated using a Mitutoyo Surftest (SV-514) which used a cut-off length of 0.8 mm and evaluation length of 4 mm. The tester uses Surfpak V4.10 (2) software with a resolution of 0.01 μm and stylus speed of 0.10 mm sec^{-1}. Each measurement of R_a was taken three times and their arithmetic mean was calculated
- **Scanning Electron Microscope (SEM) model:** Jeol JSM-5600 was used to investigate the surface integrity of wire-EDMed surfaces

The two machining processes were carried out on Mitsubishi Wire-EDM Model W11 FX2K. The machine can accommodate wire of between 0.5 and 3.5 mm diameter. In the present work, a 0.25 mm diameter brass wire was used as electrode with distilled water as dielectric fluid. The response factors selected for this study is surface roughness of the workpiece. The machining factors used for the experiments were pulse current, gap voltage and on time. Based on the three machining factors, a full-factorial experimental design was invoked from 2^k, giving a total number of eight (2^3) experimental runs each for the two machining methods (wet and dry).

Table 1: Percentage chemical composition of SUS 304 stainless steel used

Cr	Ni	Mn	Si	C
18-20	8-10.5	2	1	0.08

Table 2: Mechanical properties of SUS 304 stainless steel used

Properties	Values
Yield strength	30 ksi
Tensile strength	75 ksi
Percentage elongatin	40%
Percentage reduction	60%
Hardness	187 HB

RESULTS AND DISCUSSION

A study of the surface integrity of SUS 304 stainless steel workpiece in dry and wet wire-EDM is presented in this paper. Wire-EDM was conducted on a Mitsubishi Wire-EDM Model W11 FX2K with 0.25 mm diameter brass wire as the electrode in distilled water as dielectric fluid. A full factorial of 8 experimental runs each were carried out for the two machining techniques, giving a total number of 16 experiments for the two machining conditions. The machining parameters of current, pulse time and gap voltage were varied within the experimental range. The wire-EDMed surface morphology was examined with a Scanning Electron Microscope (SEM) model: JEOL JSM-5600, while the surface roughness R_a was evaluated using a Mitutoyo Surface Tester SV-514. Table 3 shows the wire-EDM parameters for both dry and wet conditions and the results obtained for the study.

The surface integrity of the EDMed workpiece is usually affected by uneven fusing structure particles, globules of debris, craters and voids (Lee and Tai, 2003). It can be observed from the SEM micrographs Fig. 1A that the surface integrity is similar to the theory suggested by Lee and Tai (2003). It can be seen from Fig. 1A-F that wet wire-EDM achieved better surface integrity of the workpiece compared to that of dry wire-EDM. Figure. 1A and B show the micrographs of SEM surface machined with the same machining parameters but with different machining conditions (i.e. dry and wet conditions). It can be seen that Fig. 1B has a better surface integrity with surface roughness values of 1.22 μm as against 1.51 μm that is recorded in Fig. 1A. The same result is recorded for all the surfaces wire-EDMed in wet condition.

The better surface integrity achieved by the wet wire-EDM can be attributed to the cooling effect of dielectric fluid on both the wire electrode and the workpiece which ensures smooth machining. More so, during wet wire-EDM, the adhesion of machining debris onto electrode-workpiece interface after successive erosion is reduced by the flushing effect of dielectric fluid between the workpiece and the electrode. This fact is supported by the findings of ZhanBo *et al.* (2004).

Table 3: Wire-EDM parameters and the results obtained for dry and wet wire-EDM

S/No	Pluse current	On-time (μs)	Gap voltage(V)	Surface roughness Ra(μm) Dry	Wet
1	14	3	20	1.505	1.22
2	23	6	40	1.78	1.39
3	23	3	20	1.58	1.285
4	14	3	40	1.39	1.21
5	23	6	40	1.715	1.455
6	14	3	20	1.30	1.19
7	23	6	20	1.68	1.35
8	14	6	40	1.565	1.285

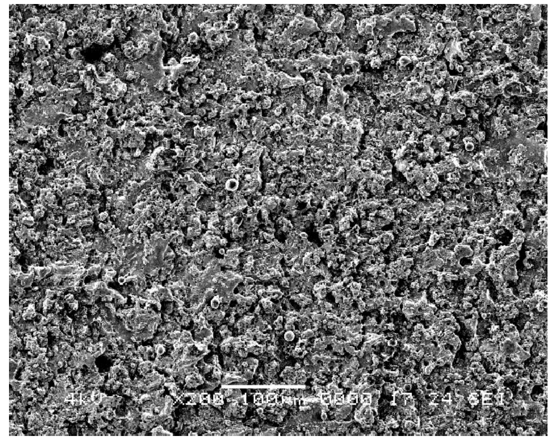

Fig. 1A: Run 1 (I = 14 A, V = 20 V: Dry-WEDM, Ra = 1.51 μm)

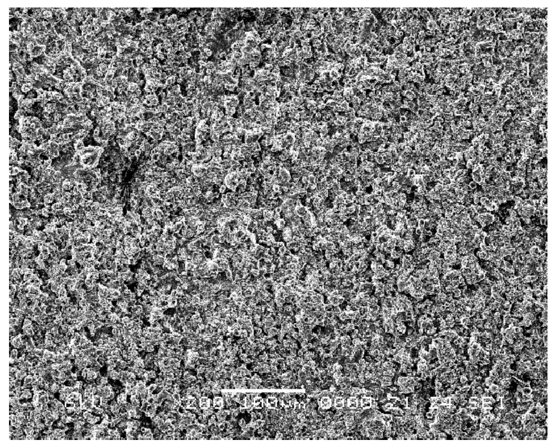

Fig. 1B: Run 1 (I = 14 A, V = 20 V: Wet-WEDM, Ra = 1.22 μm)

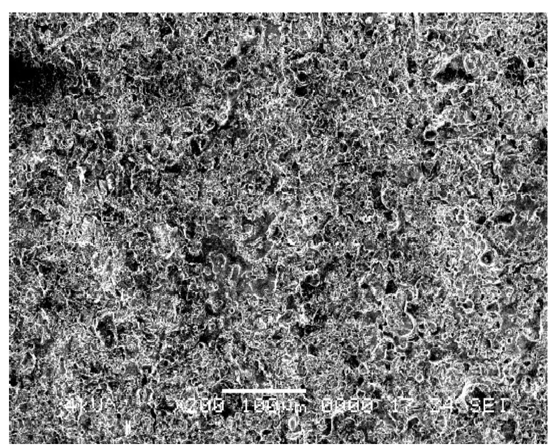

Fig. 1C: Run 5 (I = 23 A, V = 40 V: Dry-WEDM, Ra = 1.72 μm

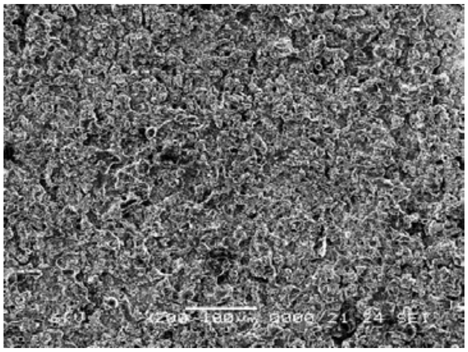

Fig. 1D: Run 5 (I = 23 A, V = 40 V: Wet-WEDM, Ra = 1.45μm)

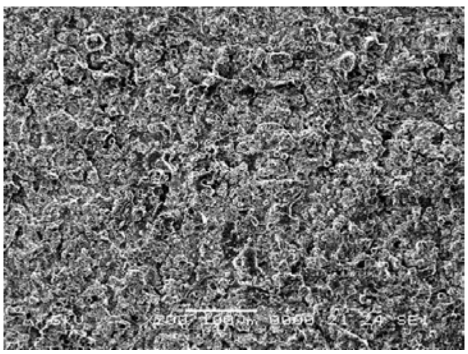

Fig. 1E: Run 7 (I = 23 A, V = 20 V: Dry-WEDM, Ra = 1.68 μm)

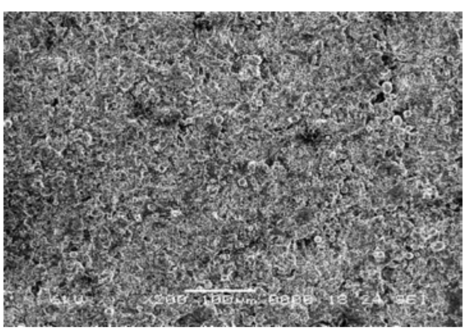

Fig. 1F: Run 7 (I = 23 A, V = 20 V: Wet-WEDM, Ra = 1.35 μm)

For the case of pulse current, experimental runs 1 and 3 as well as runs 2 and 8 (Table 3) show increase in surface roughness as current increases. It can be equally observed from Table 3 that as gap voltage increases from 20 to 40 V, surface roughness of the workpiece also increase (experiment Nos. 5 and 7 as well as No. 6 and 8).

The increase in surface roughness of the workpiece as the pulse current and gap voltage increase show that the amount of heat energy transferred to the workpiece

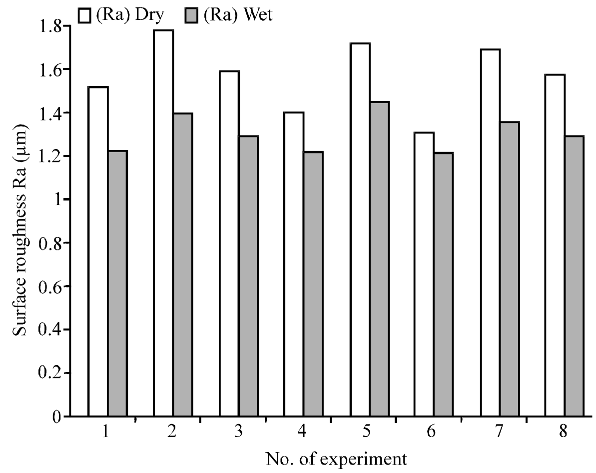

Fig. 2: Graph of surface roughness of dry and wet wire-EDM of SUS 304 stainless steel

surface is also increased. This increase in pulse current and gap voltage results in high tensile and thermal loading in inter electrodes gap. The resulting discharges as a result of the high tension, strike the surface of the workpiece more intensely and more material is melted and vapourized. This finding is in agreement with the findings of (Suleiman *et al*., 2010; Sushant *et al*., 2007; Lee and Li, 2003). Since the melted and vapourized material is not flushed away from electrode-workpiece interface during dry wire-EDM, more debris settled on the workpiece surface resulting in poor surface integrity. The effect of machining debris settling on the workpiece surface is responsible for the poor surface roughness recorded during dry wire-EDM as shown in Fig. 2.

CONCLUSION

The surface integrity of SUS 304, austenitic stainless steel during dry and wet wire-EDM as well as the effect of pulse current and gap voltage were experimentally investigated and analyzed. The main conclusions obtained in this study are as follows:

- Wet wire-EDM gives better surface integrity compared to dry wire-EDM
- During dry wire-EDM, adhesion of machining debris on the inter electrodes surface is one of the factors that is responsible for poor surface integrity resulting in poor surface finish on the workpiece
- Increase in both pulses current and gap voltage also contributes to the poor surface integrity of the workpiece during dry wire-EDM
- This study showed that wet wire-EDM method could be used to get improved surface integrity of SUS 304, austenitic stainless steel

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